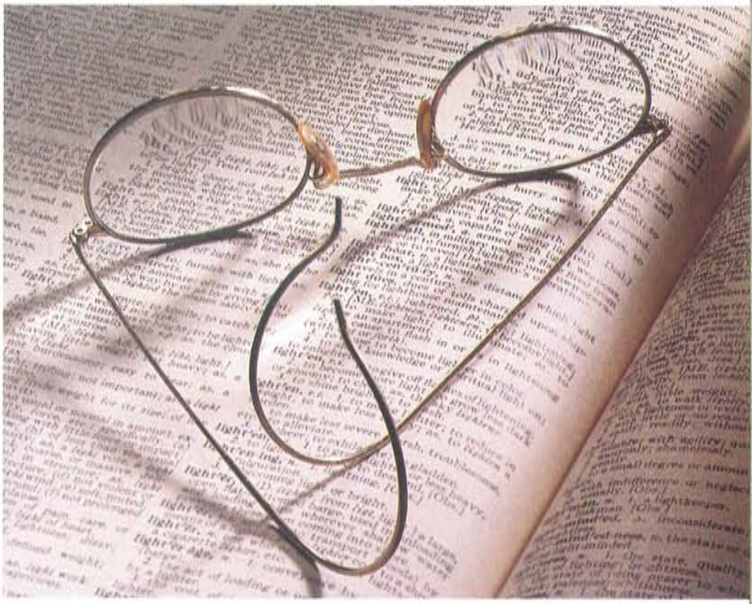
30 Lenses

Chapter 30 develops the concept of a lens, introduces the ideas of ray optics, and discusses practical applications of lenses. Background for hands-on activities and experiment.



Lenses manipulate light.

A light ray bends as it enters glass and bends again as it leaves. The bending (refraction) is due to the difference in the average speed of light in glass and in air. Glass of a certain shape can form an image that appears larger, smaller, closer, or farther than the object being viewed. For example, magnifying glasses have been used for centuries and were well known to the early Greeks and medieval Arabs. Today, eyeglasses allow millions of people to read in comfort, and cameras, projectors, telescopes, and microscopes widen our view of the world.

Skim or skip this chapter if your students don't pair this with a hands-on experience with lenses.

30.1 Converging and Diverging Lenses

Important Terms

- converging lens
- diverging lens
- focal length
- focal plane
- focal point
- lens
- principal axis

When a piece of glass has just the right shape, it bends parallel rays of light so that they cross and form an image. Such a piece of glass is a **lens.**

The shape of a lens can be understood by considering a lens to be a large number of portions of triangular prisms, as shown in Figure 30.1. When arranged in certain positions, the prisms bend incoming parallel rays so they converge to (or diverge from) a single point. The arrangement shown at the left is thicker in the middle; it

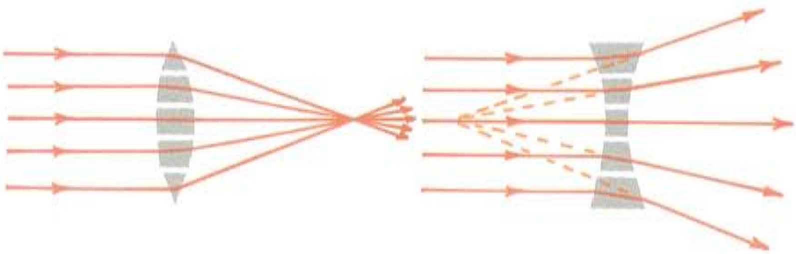


Figure 30.1
A lens may be thought of as a set of prisms that converge light (left) or diverge light (right).

converges the light. The arrangement at the right is thinner in the middle; it diverges the light.

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In both arrangements, the most net bending of rays occurs at the outermost prisms, for they have the greatest angle between the two refracting surfaces. No net bending occurs in the middle "prism," for its glass faces are parallel and rays emerge in their original direction.

Real lenses are made not of prisms, of course, but of solid pieces of glass with surfaces that are usually ground to a spherical shape. Figure 30.2 shows how smooth lenses refract rays of light and form wave fronts. The lens at the left is thicker in the middle and rays of light that are initially parallel (straight wave fronts) are made to converge. This is a **converging lens.** The lens at the right is thinner in the middle and the rays of light are made to diverge. This is a **diverging lens.**

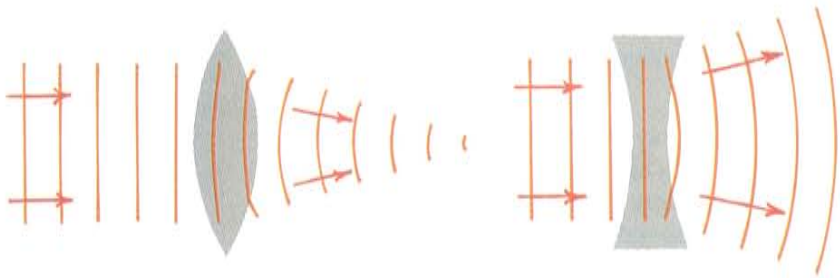

Figure 30.2 ▲
Wave fronts travel more slowly in glass than in air. In the converging lens (left), the wave fronts are retarded more through the center of the lens, and the light converges. In the diverging lens (right), the waves are retarded more at the edges, and the light diverges.

Figure 30.3 illustrates some important terms for a lens. The **principal axis** of a lens is the line joining the centers of curvature of its surfaces. For a converging lens, the **focal point** is the point at which a beam of parallel light, parallel to the principal axis, converges. Incident parallel beams that are not parallel to the principal axis focus at points above or below the focal point. All such possible points make up a **focal plane.** A lens affects light coming from the right in the same way as light coming from the left (*or* has the same effect on light incident from either side). Therefore, a lens has two focal points and two focal planes. When the lens of a camera is set for distant objects, the film is in the focal plane behind the lens in the camera.

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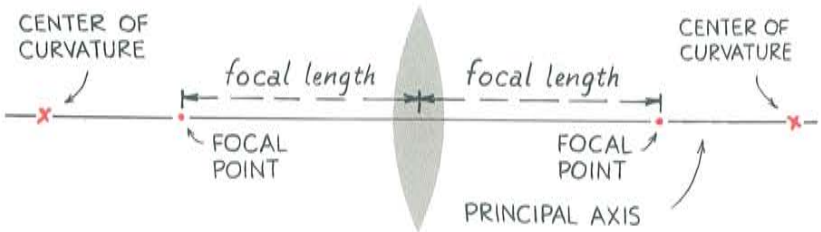


For a diverging lens, an incident beam of light parallel to the principal axis is not converged to a point, but is diverged so that the light appears to come from a point. The **focal length** of a lens, whether converging or diverging, is the distance between the center of the lens and its focal point. When the lens is thin, the focal lengths on either side are equal, even when the curvatures on the two sides are not.

Important Terms

real image
virtual image

Patiently distinguish between virtual and real images. The rays of light that show your mirror image *appear* to diverge from behind the glass—but there is no light behind the glass. Hence the *virtual image* of mirrors. The rays of light from a slide projector that focus upon a screen, in contrast, make up a *real image.*

30.2 Image Formation by a Lens

With unaided vision, an object far away is seen through a relatively small angle of view (Figure 30.4a). When you are closer, the same object is seen through a larger angle of view (Figure 30.4b). This wider angle enables the perception of more detail. Magnification occurs when an image is observed through a wider angle with the use of a lens than without the lens and allows more detail to be seen. A magnifying glass is simply a converging lens that increases the angle of view and allows more detail to be seen.

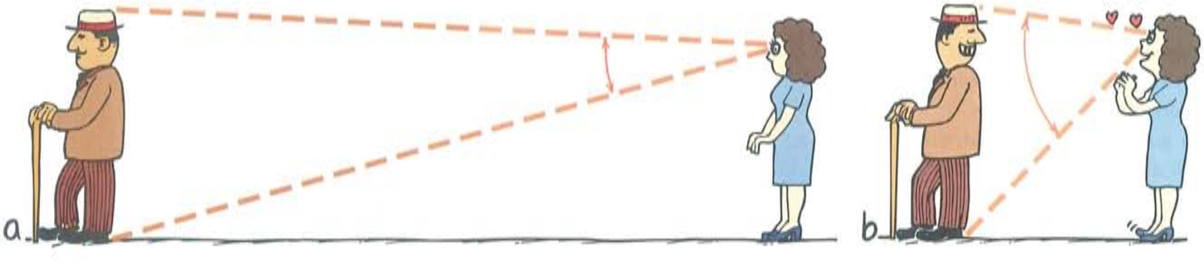


Figure 30.4 ▲
(a) A distant object is viewed through a narrow angle. (b) When the same object is viewed through a wide angle, more detail is seen.

When you use a magnifying glass, you hold it close to the object you wish to see magnified. This is because a converging lens will magnify only when the object is between the focal point and the lens. The magnified image will be farther from the lens than the object, and it will be right-side up. If a screen were placed at the image distance, no image would appear on the screen because no light is actually directed to the image position. The rays that reach your eye, however, behave *as if* they came from the image position, so the image is a **virtual image**.

When the object is far enough away to be beyond the focal point of a converging lens, light from the object does converge and can be focused on a screen (Figure 30.6). An image formed in this way by converging light is called a **real image.** A real image formed by a single converging lens is upside down (inverted). Converging lenses are used for projecting slides and motion pictures on a screen, and for projecting a real image on the film of a camera.

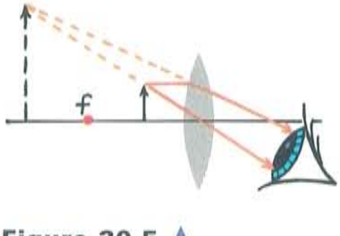
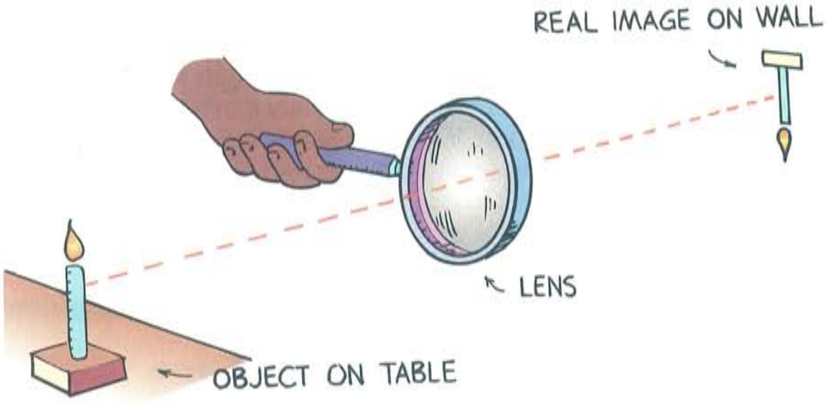


Figure 30.5 ▲
A converging lens can be used as a magnifying glass to produce a virtual image of a nearby object. The image appears larger and farther from the lens than the object.

igure 30.6 ▶
converging lens forms a real, pside-down image of a more istant object.



When a diverging lens is used alone, the image is always virtual, right-side up, and smaller than the object. It makes no difference how far or how near the object is. A diverging lens is often used for the viewfinder on a camera. When you look at the object to be photographed through the viewfinder, you see a right-side up virtual image that approximates the same proportions as the photograph to be taken.

Figure 30.7 ▶
The moving pattern of bright ines on the bottom of a swimming pool results from the uneven surface of water, which behaves as a moving blanket of enses.

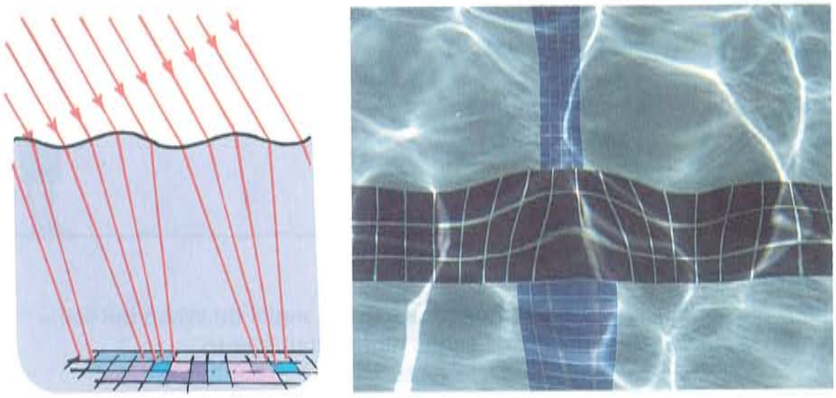


Figure 30.8 ▲
A virtual image produced by a diverging lens.

■ **Question**

Why is the greater part of the photograph in Figure 30.8 out of focus?

■ **Answer**

Both Jamie and his cat and the virtual image of Jamie and his cat are "objects" for the lens of the camera that took this photograph. Since the objects are at different distances from the camera lens, their respective images are at different distances with respect to the film in the camera. So only one can be brought into focus. The same is true of your eyes. You cannot focus on near and far objects at the same time.

30.3 Constructing Images Through Ray Diagrams

Important Term

ray diagram

Reproduce Figure 30.9 on the board or overhead projector using colored chalk or pens. Differentiate between the lens, principal axis, and rays.

Ray diagrams, like the one in Figure 30.9, show the principal rays that can be used to determine the size and location of an image. To construct a ray diagram the size and location of the object, its distance from the center of the lens, and the focal length of the lens must be known.* An arrow is used to represent the object (which may be anything from a microbe viewed in a microscope to a galaxy viewed through a telescope). For simplicity, one end of the object is placed right on the principal axis.

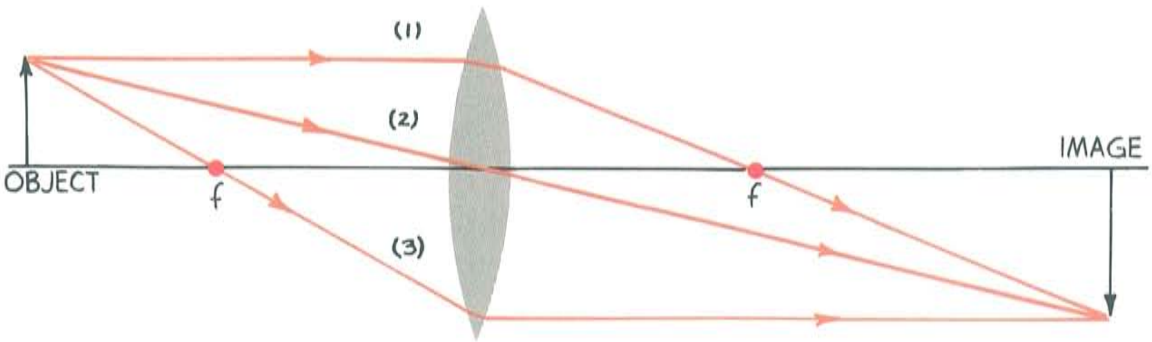


Figure 30.9 ▲
Ray diagram. Three useful rays from the object that converge on the image.

Stress that the three rays shown in Fig. 30.9 are samples of an infinite number of rays leaving every part of the object. If the top part of the lens were covered, for example, the entire image would appear as with a full lens, only dimmer. A common misconception is that when part of the lens is blocked only part of the image appears.

Show by demo, or better by lenses in the hands of students, how changing object position changes image position. It's important that students see ray diagrams are a useful tool for representing what they see.

To locate the position of the image, you only have to know the paths of two rays from a point on the object. Any point except for the point on the principal axis will work, but it is customary to choose a point at the tip of the arrow.

The path of one refracted ray is known from the definition of the focal point. A ray parallel to the principal axis will be refracted by the lens to the focal point, as shown in Figure 30.9.

Another path is known: through the center of the lens where the faces are parallel to each other. A ray of light will pass through the center with no appreciable change in direction. Therefore, a ray from the tip of the arrowhead proceeds in a straight line through the center of the lens.

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* The mathematical relationship between object distance o, image distance i, and focal length f is given by

$$\frac{1}{o} + \frac{1}{i} = \frac{1}{f}$$

This is called the *thin-lens equation.*

A third path is known: A ray of light that passes through the focal point in front of the lens emerges from the lens and proceeds parallel to the principal axis.

All three paths are shown in Figure 30.9, which is a typical ray diagram. The image is located where the three rays intersect. Any two of these three rays is sufficient to locate the relative size and location of the image.

The ray diagram for a converging lens used as a magnifying glass is shown in Figure 30.10. In this case, where the distance from the lens to the object is less than the focal length, the rays diverge as they leave the lens. The rays of light appear to come from a point in front of the lens (same side of the lens as the object). The location of the image is found by extending the rays backward to the point where they converge. The virtual image that is formed is magnified and right-side up.

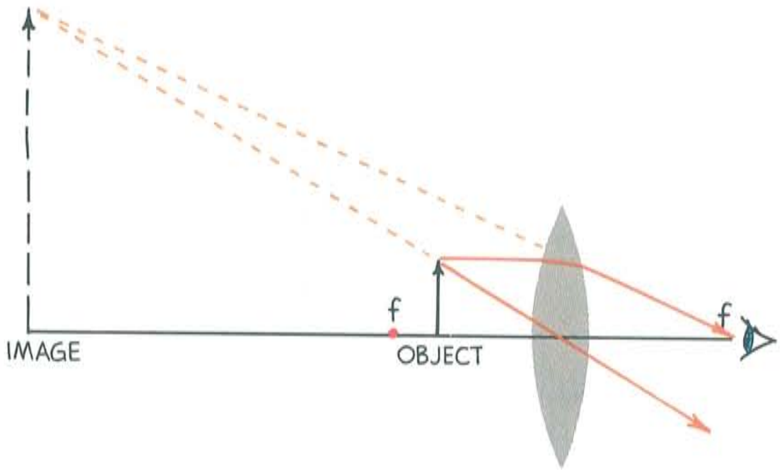


Figure 30.10 ▲
Ray diagram for a magnifying glass. The object is less than one focal length from the lens, so the image is virtual, right-side up, and magnified.

his summary of ray diagram onstruction is well worth class me.

The three rays useful for the construction of a ray diagram are summarized:

1. A ray parallel to the principal axis that passes through the focal point after refraction by the lens.
2. A ray through the center of the lens that does not change direction.
3. A ray through the focal point in front of the lens that emerges parallel to the principal axis after refraction by the lens.

Any two rays are sufficient to locate an image; which particular pair is chosen is merely a matter of convenience.

The ray diagrams in Figure 30.11 show image formation by a converging lens as an object initially at the focal point is moved away from the lens along the principal axis. Since the object is not located between the focal point and the lens, all the images that are formed are real and inverted.

Object position: distance *f* from lens (at the focal point)
Image position: at infinity

Object position: between *f* and 2*f* from lens
Image position: beyond 2*f* from lens
Image size: magnified

Object position: distance 2*f* from lens
Image position: distance 2*f* from lens
Image size: same as object

Object position: beyond 2*f* from lens
Image position: between *f* and 2*f* from lens
Image size: smaller

Object position: at infinity
Image position: distance *f* from lens (at the focal point)

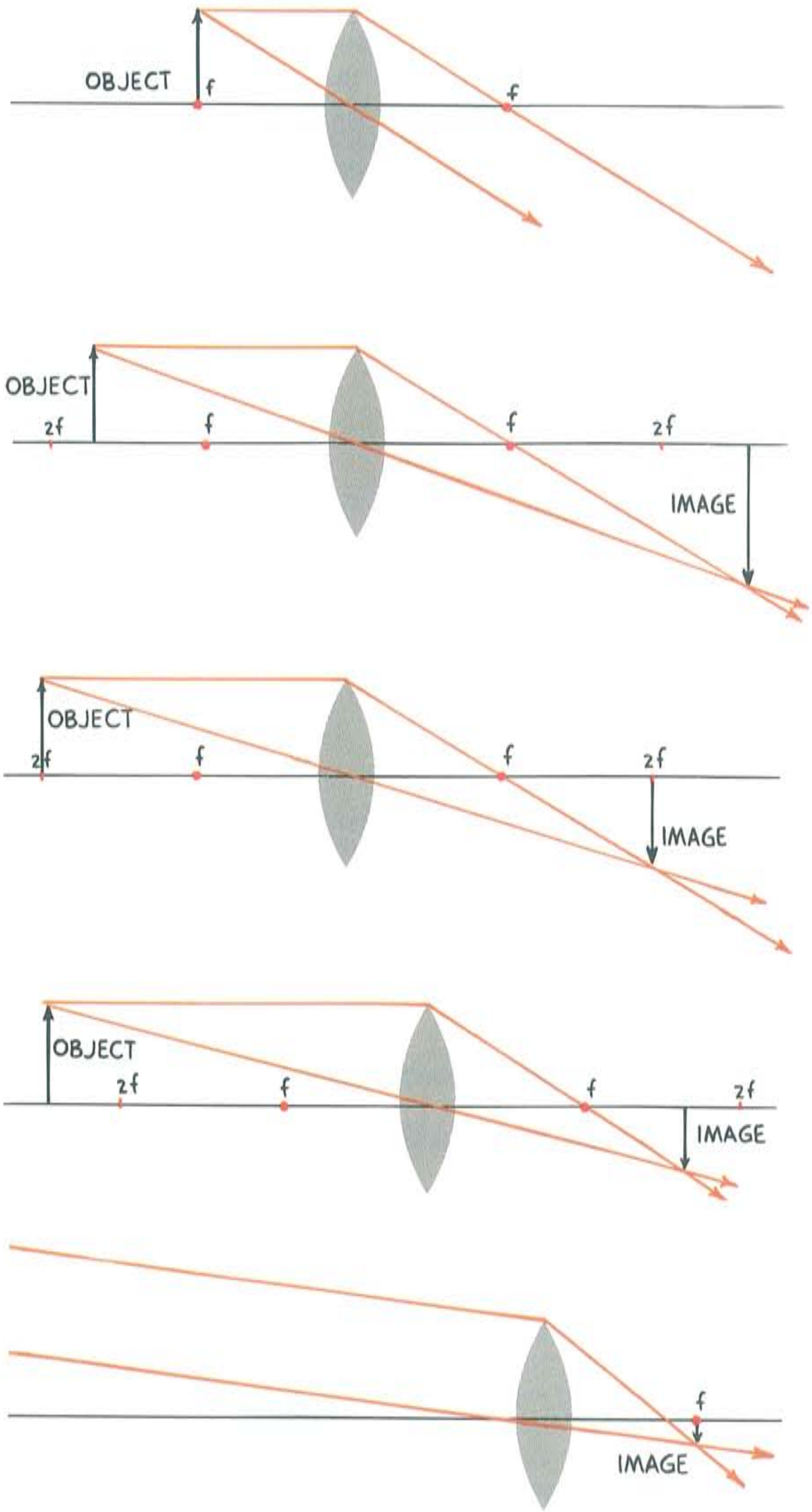


Figure 30.11 ▲
Ray diagrams for different positions of an object in relation to a converging lens of focal length *f*.

Demonstration: If the Fig. 30.11 ray diagrams have not been done as a laboratory exercise, demonstrate them in class. Darken the room and use an unfrosted bulb or a candle on an optical bench with length markings. A converging lens with a focal length of 20–25 cm works nicely.

Draw Figure 30.12 on the board or overhead projector using colored chalk or pens. Differentiate between the lens, principal axis, and rays.

The method of drawing ray diagrams applies also to diverging lenses (Figure 30.12). A ray parallel to the principal axis from the tip of the arrow will be bent by the lens in the same direction as if it had come from the focal point. A ray through the center goes straight through. A ray that is heading for the focal point on the far side of the lens is bent so that it emerges parallel to the axis of the lens.

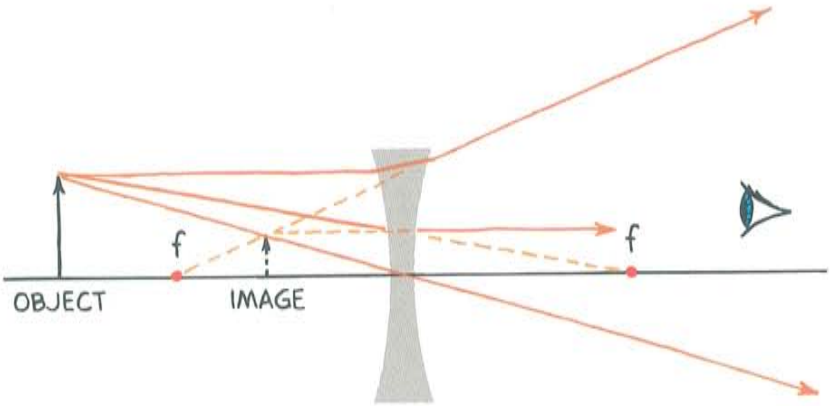


Figure 30.12 ▲
Ray diagram for a diverging lens.

On emerging from the lens, the three rays appear to come from a point on the same side of the lens as the object. This point defines the position of the virtual image. The image is nearer the lens than the object. It is smaller than the object and right-side up. Regardless of the object's position, the image formed by a diverging lens is always virtual, reduced, and right-side up.

30.4 Image Formation Summarized

A converging lens is a simple magnifying glass when the object is within one focal length of the lens. The image is then virtual, magnified, and right-side up.

When the object is beyond one focal length, a converging lens produces a real, inverted image. The location of the image depends on how close the object is to the focal point. If it is close to the focal point, the image is far away (as with a slide projector or movie projector). If the object is far from the focal point, the image is nearer (as with a camera). In all cases where a real image is formed, the object and the image are on opposite sides of the lens.

When the object is viewed with a diverging lens, the image is virtual, reduced, and right-side up. This is true for all locations of the object. In all cases where a virtual image is formed, the object and the image are on the same side of the lens.

■ **Question**

Where must an object be located so that the image formed by a converging lens will be (a) at infinity? (b) as near the object as possible? (c) right-side up? (d) the same size? (e) inverted and enlarged?

30.5 Some Common Optical Instruments

Important Terms

eyepiece
objective lens

The advent of eyeglasses probably occurred in Italy in the late 1200s. If anybody viewed objects through a pair of lenses held far apart, one in front of the other, there is no record of it, for curiously enough, the telescope wasn't invented until some 300 years later. Today, lenses are used in many optical instruments. Among these are the camera, telescope (and binoculars), compound microscope, and projector.

Show students a camera and camera lens. Point out the diaphragm and focusing mechanism.

The Camera

A camera consists of a lens and sensitive film mounted in a lighttight box. In many cameras, the lens is mounted so that it can be moved back and forth to adjust the distance between the lens and film. The lens forms a real, inverted image on the film.

Figure 30.13 shows a camera with a single simple lens. In practice, most cameras make use of compound lenses to minimize distortions called *aberrations*.

The amount of light that gets to the film is regulated by a shutter and a diaphragm. The shutter controls the length of time that the film is exposed to light. The diaphragm controls the opening that light passes through to reach the film. Varying the size of the opening (aperture) varies the amount of light that reaches the film at any instant.

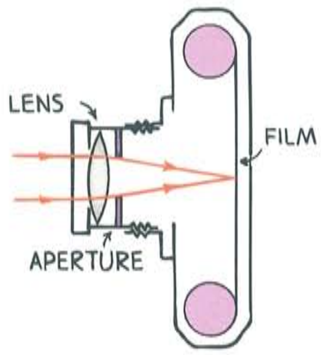


Figure 30.13 ▲
A simple camera.

The Telescope

A simple telescope uses a lens to form a real image of a distant object. The real image is not caught on film but is projected in space to be examined by another lens used as a magnifying glass. The second lens, called the **eyepiece,** is positioned so that the image produced by the first lens is within one focal length of the eyepiece. The eyepiece

The telescope was invented in 1608 by Dutch optician Hans Lippershey.

If a refracting astronomical telescope is available, show it to the students. In better telescopes, the primary lens has a concave corrector lens with it.

Show students a terrestrial telescope and a pair of binoculars.

■ **Answer**

The object should be (a) one focal length from the lens (at the focal point) (see Figure 30.11); (b) and (c) within one focal length of the lens (see Figure 30.10); (d) at two focal lengths from the lens (see Figure 30.11); (e) between one and two focal lengths from the lens (see Figure 30.11).

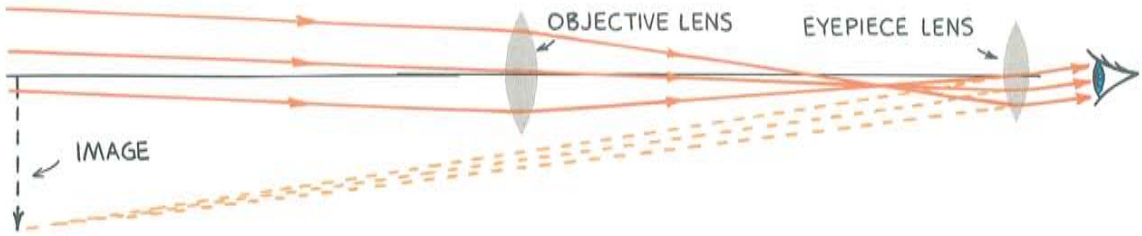
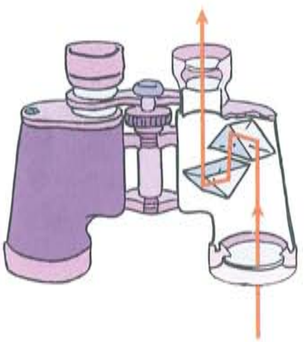


Figure 30.14 ▲
Lens arrangement for an astronomical telescope. (For simplification, the image is shown close here; it is actually located at infinity.)



igure 30.15 ▲
he arrangement of prisms in inoculars.

forms an enlarged virtual image of the real image. When you look through a telescope, you are looking at an image of an image.

Figure 30.14 shows the lens arrangement for an *astronomical telescope.* The image is inverted, which explains why maps of the moon are printed with the moon upside down.

A third lens or a pair of reflecting prisms is used in the *terrestrial telescope,* which produces an image that is right-side up. A pair of these telescopes side by side, each with a pair of prisms to provide four reflecting surfaces to turn images right-side up, makes up a pair of *binoculars* (Figure 30.15).

Since no lens transmits 100% of the light incident upon it, astronomers prefer the brighter, inverted images of a two-lens telescope to the less bright, right-side-up images that a third lens or prisms would provide. For nonastronomical uses, such as viewing distant landscapes or sporting events, right-side-up images are more important than brightness, so the additional lens or prisms are used.

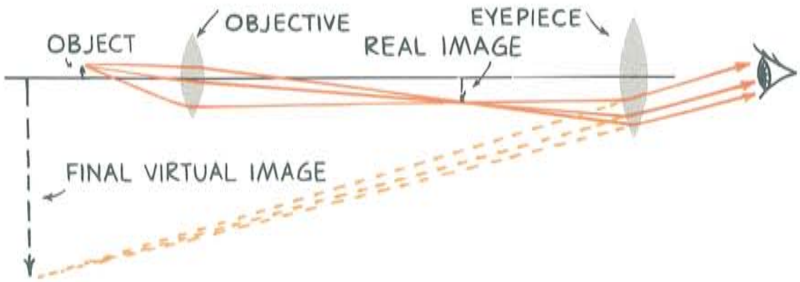
Telescopes that use lenses are *refracting telescopes.* Larger astronomical telescopes use mirrors instead of lenses.

The Compound Microscope

how a compound microscope rom a biology teacher).

A compound microscope uses two converging lenses of short focal length, arranged as shown in Figure 30.16. The first lens, called the **objective lens,** produces a real image of a close object. Since the image is farther from the lens than the object, it is enlarged. A second lens, the eyepiece, forms a virtual image of the first image, further enlarged. The instrument is called a compound microscope because it enlarges an already enlarged image.

igure 30.16 ▶
ens arrangement for a compound microscope.



The Projector

The arrangement of converging lenses for a slide or movie projector is shown in Figure 30.17. A concave mirror reflects light from an intense source back onto a pair of *condenser lenses*. The condenser lenses direct the light through the slide or movie frame to a *projection lens*. The projection lens is mounted in a sliding tube so that it can be positioned back and forth to focus a sharp image on the screen.

A film or slide projector can be opened up and demonstrated.

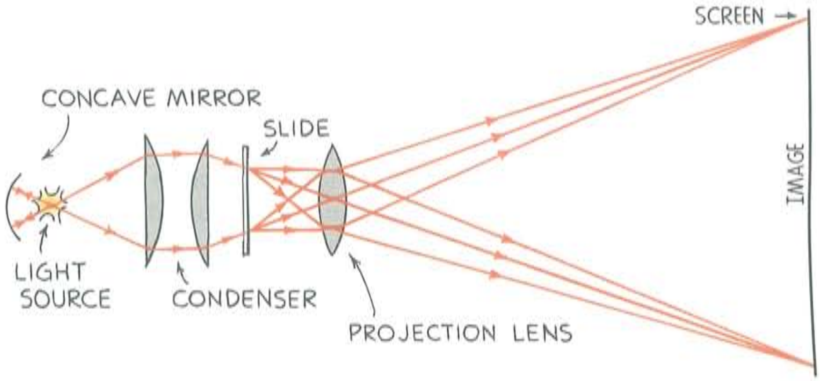


Figure 30.17 ▲
Lens arrangement for a projector.

30.6 The Eye

Important Terms

cornea
iris
pupil
retina

In many respects the human eye is similar to the camera. The amount of light that enters is regulated by the **iris,** the colored part of the eye that surrounds the opening called the **pupil.*** Light enters through the transparent covering called the **cornea,** passes through the pupil and lens, and is focused on a layer of tissue at the back of the eye—the **retina**—extremely sensitive to light. Different parts of the retina receive light from different directions.

The retina is not uniform. There is a small region in the center of our field of view where we have the most distinct vision. This spot is called the *fovea*. Much greater detail can be seen here than at the side parts of the eye.

There is also a spot in the retina where the nerves carrying all the information leave the eye in a narrow bundle. This is the *blind spot*. You can demonstrate that you have a blind spot in each eye if you hold this book at arm's length, close your left eye, and look at the circle in Figure 30.19 with only your right eye. You can see both the circle and the X at this distance. If you now move the book slowly

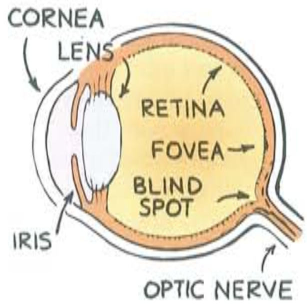


Figure 30.18 ▲
The human eye.

* The hole of the pupil usually looks black because light is going in but not coming out. Sometimes in flash photos, the light from the flashbulb enters the eye at just the right angle to reflect off the retina at the back of the eye. That's why flash photographs sometimes show the pupils to be pinkish.

ats' eyes, and those of whales, olphins, horses, fish, crocoiles, and other creatures have reflecting layer of cells just ehind the retina, called the *apetum*. This design reflects ght within the eye so that light hat may miss a photoreceptor pon arriving at the retina has second chance when it is eflected. The tapetum is the rigin of the "glowing" of

PHYSICS ON THE JOB

Photographer

Photography blends art with physics. A photographer's ideas are based on artistry, but their execution relies on a savvy use of physics technology. A photographer knows that camera film seldom is able to record what our eyes see. Our eyes can discern detail simultaneously both in dark shadows and in light that is millions of times brighter; camera film can't. Hence, the photographer is concerned with and experiments with contrast. The photographer who has knowledge of the physics of light and optics is better able to understand and keep up with the changes provided by an expanding technology—newer films and newer imaging techniques.

toward your face, with your right eye still fixed upon the circle, you'll reach a position about 20 to 25 cm from your eye where the X disappears. To establish the blind spot in your left eye, close your right eye and similarly look at the X with your left eye so that the circle disappears. With both eyes opened, you'll find no position where either the X or the circle disappears because one eye "fills in" the part of the object to which the other eye is blind. It's nice to have two eyes.

Figure 30.19 ▲
For the blind spot experiment.

In both the camera and the eye, the image is upside down, and this is compensated for in both cases. You simply turn the camera film around to look at it. Your brain has learned to turn around images it receives from your retina!

A principal difference between a camera and the human eye has to do with focusing. In a camera, focusing is accomplished by altering the distance between the lens and the film. In the human eye, most of the focusing is done by the cornea, the transparent membrane at the outside of the eye. Adjustments in focusing of the image on the retina are made by changing the thickness and shape of the lens to regulate its focal length. This is called *accommodation* and is brought about by the action of the *ciliary muscle*, which surrounds the lens.

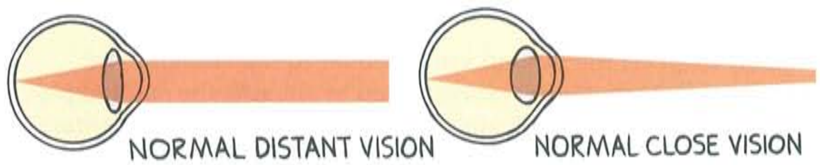


Figure 30.20 ▲
The shape of the lens changes to focus light on the retina.

30.7 Some Defects in Vision

If you have what is called normal vision, your eye can accommodate to clearly see objects from infinity (the *far point*) down to 25 cm (the *near point*, which normally recedes for all people with advancing age).

The eyes of a **farsighted** person form images behind the retina (Figure 30.21). The eyeball is too short. Farsighted people have to hold things more than 25 cm away to be able to focus them. The remedy is to increase the converging effect of the eye. This is done by wearing eyeglasses or contact lenses with converging lenses. Converging lenses will converge the rays that enter the eye sufficiently to focus them on the retina instead of behind the retina.

Figure 30.21 ▲
The eyeball of the farsighted eye is too short. A converging lens moves the image closer and onto the retina.

some animals' eyes when seen at night by means of a flashlight or auto headlights.

A dissected sheep's eye or a model of the eye may be available from the biology department. Note the connection between physics and biology.

Have the students do the blind spot experiment.

A **nearsighted** person can see nearby objects clearly, but does not see distant objects clearly because they are focused too near the lens, in front of the retina (Figure 30.22). The eyeball is too long. A remedy is to wear corrective lenses that diverge the rays from distant objects so that they focus on the retina instead of in front of it.

Important Terms

astigmatism
farsighted
nearsighted

In Figure 30.21, it appears that the outside of the lens is convex and the inside is concave. This is true, but the lens is thicker in the center than at the edges. Hence, it is a converging lens.

In Figure 30.22, it appears that the outside of the lens is convex and the inside is concave. This is true, but the lens is thinner in the center than at the edges. Hence, it is a diverging lens.

Figure 30.22 ▲
The eyeball of the nearsighted eye is too long. A diverging lens moves the image farther away and onto the retina.

Astigmatism of the eye is a defect that results when the cornea is curved more in one direction than the other, somewhat like the side of a barrel. Because of this defect, the eye does not form sharp images. The remedy is cylindrical corrective lenses that have more curvature in one direction than in another.

30.8 Some Defects of Lenses

Important Term

aberration

No lens gives a perfect image. The distortions in an image are called **aberrations.** By combining lenses in certain ways, aberrations can be minimized. For this reason, most optical instruments use compound lenses, each consisting of several simple lenses, instead of single lenses.

Spherical aberration results when light passes through the edges of a lens and focuses at a slightly different place from light passing through the center of the lens (Figure 30.23). This can be remedied by covering the edges of a lens, as with a diaphragm in a camera. Spherical aberration is corrected in good optical instruments by a combination of lenses.

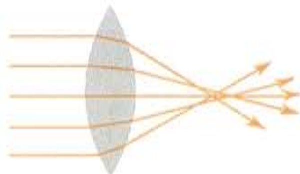
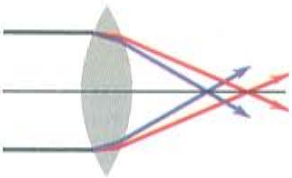


Figure 30.23 ▲
Spherical aberration.

emonstration: Spherical aberration occurs in parallel beams light passing through a con-x lens. Make sure that the eams of light go through the lges as well as the center of e lens. At the focus, a circle unfocused light is formed e to the spherical aberration. sing a diaphragm, show how e focus is improved by limit-g the aperture. If a diaphragm not available, use paper or rdboard with holes of differ-t sizes.



gure 30.24 ▲
romatic aberration.

emonstration: Send a wide am of white light through a nverging lens. Looking care-ly near the focus, note that ferent colors focus at differ-t points.

DOING PHYSICS

Pinhole Image

Poke a tiny hole in a piece of paper or card. Hold it in front of your eye close to this page. Whether or not you normally wear glasses, you'll see the print clearly. Because you're close, the print will seem magnified. Why is bright light needed? What advice do you have for someone who wears glasses and misplaces them, and can't see the small print in a telephone book?

Activity

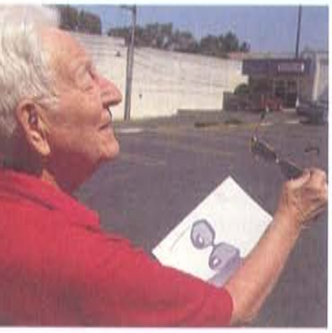
Chromatic aberration is the result of the different speeds of light of various colors and hence the different refractions they undergo. In a simple lens red light and blue light bend by different amounts (as in a prism), so they do not come to focus in the same place. *Achromatic lenses*, which combine simple lenses of different kinds of glass, correct this defect.

In the eye, vision is sharpest when the pupil is smallest because light then passes through only the center of the eye's lens, where spherical and chromatic aberrations are minimal. Also, light bends the least through the center of a lens, so minimal focusing is required for a sharp image. You see better in bright light because your pupils are smaller.

■ Question

Why is there chromatic aberration in light that passes through a lens, but no chromatic aberration in light that reflects from a mirror?

An option for those with poor sight in the last five hundred years has been to wear spectacles, and in more recent times another option has been to wear contact lenses. It is interesting to note that at the present time there is an alternative to both spectacles and contact lenses for people with poor eyesight. Experimental and controversial techniques today allow eye surgeons to reshape the cornea of the eye for normal vision. In tomorrow's world, the wearing of eyeglasses and contact lenses may be a thing of the past. We really do live in a rapidly changing world. And that can be nice.



gure 30.25 ▲
ocal eyeglasses have two sets lenses with different focal gths. As Charlie Spiegel ows here, the smaller lenses ve a shorter focal length and for close-up viewing.

■ Answer

Different frequencies travel at different speeds in a transparent medium, and therefore refract at different angles, which produces chromatic aberration. The angles at which light *reflects*, on the other hand, have nothing to do with the frequency of light. One color reflects the same as any other. Mirrors are therefore preferable to lenses in telescopes because there is no chromatic aberration with reflection.

30 Chapter Review

For fuller explanations, see the TE notes in the front of this book.

Concept Summary

A lens refracts parallel rays of light so that they cross—or appear to cross—at a focal point.

- A converging lens is thicker in the middle; a diverging lens is thinner in the middle.
- A converging lens forms virtual, magnified images when the object is within one focal length of the lens.
- A converging lens forms real images when the object is beyond one focal length from the lens.
- A diverging lens always forms virtual, reduced images.
- Optical instruments that use lenses include the camera, telescope, compound microscope, and projector.
- The human eye refracts light and focuses it on the retina (with the help of corrective lenses if necessary).

Important Terms

aberration (30.8)	iris (30.6)
astigmatism (30.7)	lens (30.1)
converging lens (30.1)	nearsighted (30.7)
cornea (30.6)	objective lens (30.5)
diverging lens (30.1)	principal axis (30.1)
eyepiece (30.5)	pupil (30.6)
farsighted (30.7)	ray diagram (30.3)
focal length (30.1)	real image (30.2)
focal plane (30.1)	retina (30.6)
focal point (30.1)	virtual image (30.2)

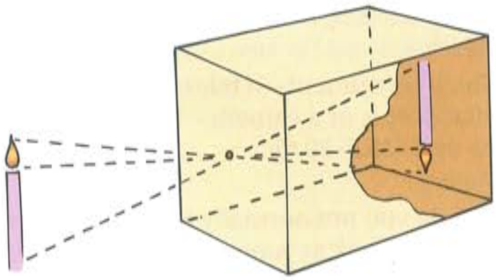
Review Questions

Recall of key chapter ideas

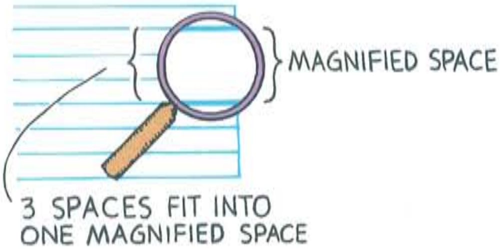
1. Distinguish between a *converging* lens and a *diverging* lens. (30.1) Conv thicker in middle; div thinner in middle
2. Distinguish between the focal *point* and focal *plane* of a lens. (30.1) Focal pt is single pt on prin axis; foc plane is area perp to prin axis
3. Distinguish between a *virtual* image and a *real* image. (30.2) Only a real image can be projected on a screen.
4. There are three convenient rays commonly used in ray diagrams to estimate the position of an image. Describe these three rays in terms of their orientation with respect to the principal axis and focal points. (30.3) Parallel to prin axis; thru focal point; thru middle
5. How many of the rays in Question 4 are necessary for estimating the position of an image? (30.3) Any two
6. Do ray diagrams apply only to converging lenses, or to diverging lenses also? (30.3) Both
7. Explain what is meant by saying that in a telescope one looks at the image of an image. (30.5) Eyepiece views image of objective lens
8. In what two ways does an astronomical telescope differ from a terrestrial telescope? (30.5) Terr telescope has prisms or extra lens; image rt side-up
9. How does a compound microscope differ from a telescope? (30.5) Enlarges an already enlarged image
10. Which instrument—a telescope, a compound microscope, or a camera—is most similar to the eye? (30.5–30.6) Camera
11. Why do you not normally notice a blind spot when you look at your surroundings? (30.6) Your other eye fills in the blind spot.
12. Distinguish between *farsighted* and *nearsighted* vision. (30.7) Farsighted, image behind retina: nearsighted, in front
13. What is astigmatism, and how can it be corrected? (30.7) Cornea curved like barrel; cylindrical lens
14. Distinguish between *spherical* aberration and *chromatic* aberration, and cite a remedy for each. (30.8) Lens' edge poor focus; colors poor focus; special lens

ctivities

Make a pinhole camera, as illustrated in the figure. Cut out one end of a small cardboard box, and cover the end with tissue or onion-skin paper. Make a clean-cut pinhole at the other end. (If the cardboard is thick, place a piece of metal foil over an opening in the cardboard, and make the hole in the foil.) Aim the camera at a bright object in a darkened room, and you will see an upside-down image on the translucent tissue paper. If in a dark, windowless room you replace the tissue paper with unexposed photographic film, cover the back so it is lighttight, and cover the pinhole with a removable flap, you will be ready to take a picture. Exposure times differ, depending mostly on the kind of film and the amount of light. Try different exposure times, starting with about 3 seconds. Also try boxes of various lengths. You'll find everything in focus in your photographs, but the pictures will not have clear-cut, sharp outlines. The principal difference between your pinhole camera and a commercial one is the glass lens, which is larger than the pinhole and therefore admits more light in less time. It is because a lens camera is so fast that the pictures it takes are called "snapshots."



. Note the shapes of light spots that reach the ground in the shade of a tree. Most of them are circular, or elliptical if the sun is low in the sky. The spots are "pinhole" images of the sun, which occur when the opening in the leaves above is small compared with the distance to the ground below. This is dramatic at the time of a partial solar eclipse, when the spots take the form of crescents. Physics is truly everywhere!



3. Determine the magnification power of a lens by focusing on the lines of a ruled piece of paper. Count the spaces between the lines that fit into one magnified space, and you have the magnification power of the lens. For example, if three spaces fit into one magnified space, then the magnification power of the lens is 3. You can do the same with binoculars and a distant brick wall. Hold the binoculars so that only one eye looks at the bricks through the eyepiece while the other eye looks directly at the bricks. The number of bricks, as seen with the unaided eye, that will fit into one magnified brick gives the magnification of the instrument.

Think and Explain

Conceptual development through applied critical thinking

1. **a.** What condition must exist for a converging lens to produce a virtual image? Object between focal point and lens

   b. What condition must exist for a diverging lens to produce a real image? None, never does

2. How could you demonstrate that an image was indeed a real image? Show it on a screen.

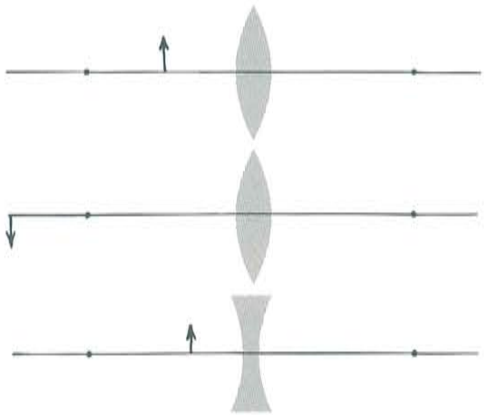
3. Why do you suppose that a magnifying glass has often been called a "burning glass"? Lens can focus sunlight and start fire.

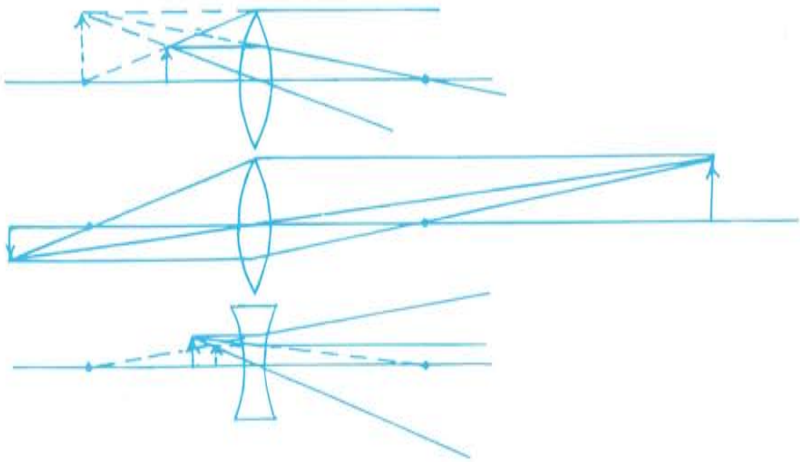
4. In terms of focal length, how far is the camera lens from the film when very distant objects are being photographed? Film is at focal point for very distant viewing.

5. Can you photograph yourself in a mirror and focus the camera on both your image and the mirror frame? Explain. No, image is behind mirror

6. If you take a photograph of your image in a plane mirror, how many meters away should you set your focus if you are 2 meters in front of the mirror?
4 m

7. Copy the three drawings in the figure. Then use ray diagrams to find the image of each arrow.





8. Why do you have to put slides into a slide projector upside down? Because its real images are upside down

9. Maps of the moon are actually upside down. Why is this so? To match inverted virtual telescope image

10. What is responsible for the rainbow-colored fringe commonly seen at the edges of a spot of white light from the beam of a slide projector? Chromatic aberration, lens edge acts as prism

11. Would telescopes and microscopes magnify if light had the same speed in glass as in air? Explain. No, there would be no refraction; no focusing

12. Consider a simple magnifying glass under water. Will it magnify more or less? Explain why. Less; less refraction—smaller Δv from water glass